APPENDIX A: ANTENNA CALIBRATION

The transmitter and receiver antennas were calibrated in a variety of environments. This is especially important for the receive antennas, which were inexpensive monopoles with limited calibration data available from the manufacturer's. The 440 MHz transmit dipole also had poor calibration data. The 1360 MHz and 1920 MHz transmit dipole antennas were high quality and had manufacturers calibration data which agree with our measurements. Calibrations consisted of two far-field tests which included the measurement vehicle and a third test which utilized the NIST anechoic chamber. The NIST test used a circular ground plane for the monopole antennas.

The first far-field test utilized a calibrated EMCO horn antenna for the 1360 MHz and 1920 MHz source and a calibrated Antenna Specialists discone antenna at 440 MHz. The source antenna gains are listed in Table A1.

Table A1. Source Antenna Gain Data used for the Far-Field Tests

Frequency(MHz)	Manufacturer	Gain(dBi)
440	Antenna Specialists	14
1360	EMCO	7.5
1920	EMCO	7.8

For this test, transmit antennas were positioned on the roof of wing 4 of the Radio Building and the van was parked east of wing 2 along the south access road. The radio path is approximately 148 m and the elevation difference is 10.4 m. The van was oriented broadside to the transmit antennas at 5 sites 1 m apart. The elevation angle was approximately 4°. Measurements were made on two separate days and averaged. The azimuth pattern of the 1360 MHz transmitter dipole was also measured. Averaged gain measurements for the field trail antennas are summarized in Tables A2 and A3.

Table A2. Gain Measurements for the Receiving Antennas

Frequency(MHz)	Manufacturer	Antenna Gain(dBi) Specification	Antenna Gain(dBi) Measured
440	Larson 5/8 λ monopole	5.2	4.8
1360(low)	Larson 1/4 λ monopole	None	-3.4
1920	Andrew PCS monopole	3	.75

Table A3. Gain Measurements for the Transmitting Antennas

Frequency (MHz)	Manufacturer	Gain(dBi) Specification	Gain(dBi) Measured
440	Cushcraft FRX430 omni directional dipole	5	0.55
1360	Dorne&Margolin DM-Q130-1 directional	12	11.33
1920	Andrew PCS-0190A-006 omni directional	6.9	6.9

Pattern measurements for the D&M antenna are given in Table A4. These results agreed well with the 360° pattern supplied by the manufacturer. The manufacturer's data was used to create a lookup table.

Table A4. 1360 MHz Dorne & Margolin Gain Measurements versus Azimuth Angle

G(0°)	G(90°)	G(180°)	G(270°)
11.3 dBi	7.3 dBi	1.3 dBi	4.3 dBi

A second set of far field tests were made at the ITS Table Mountain site, where a 360° azimuth pattern measurement of the receiving antennas and measurement van combination could be made. These tests were made at three distances at an elevation angle of 0°. The source antennas used were the same as in Table A1 except for the 440 MHz measurement, which utilized the 440 MHz Cushcraft dipole. The 440 MHz source gain has been adjusted to reflect the calibration of this antenna in the NIST chamber, as reported in the last section of this appendix. The average gain measurement over all angles and distances is given in Table A5. Figure A1 is the 360° pattern showing the influence of the van and shadowing by the mast on the roof. On this plot, 0° gives results for the van pointed head on to the calibration antenna. Also included are results for a 1360 MHz trailer mounted antenna.

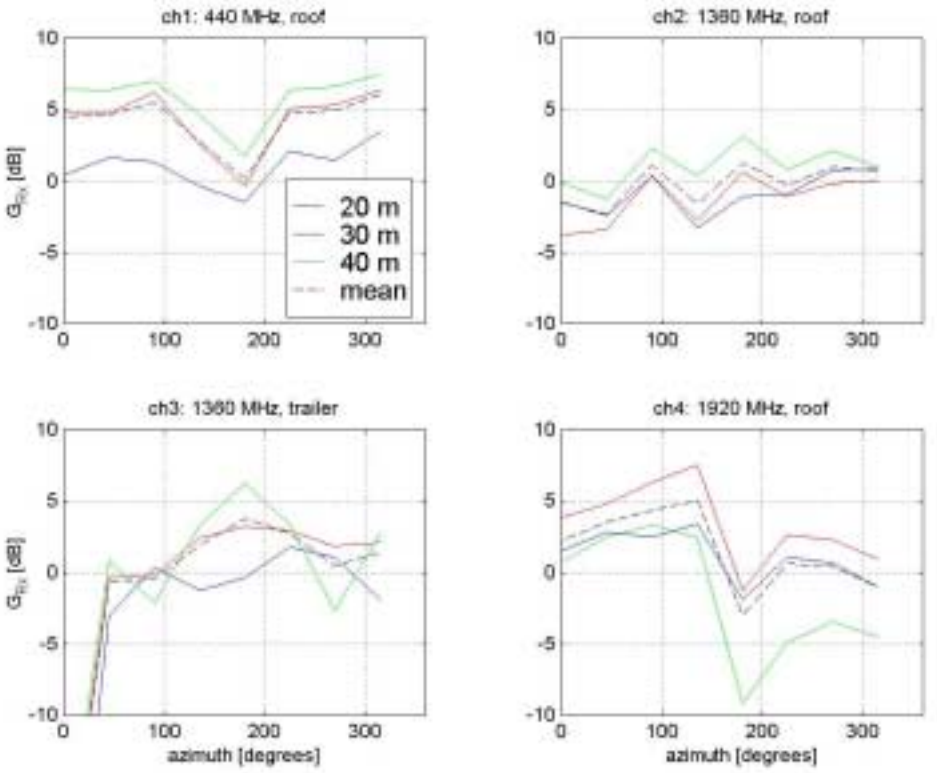

Figure A1. Antenna patterns measured at Table Mountain showing gain above isotropic versus van azimuth.

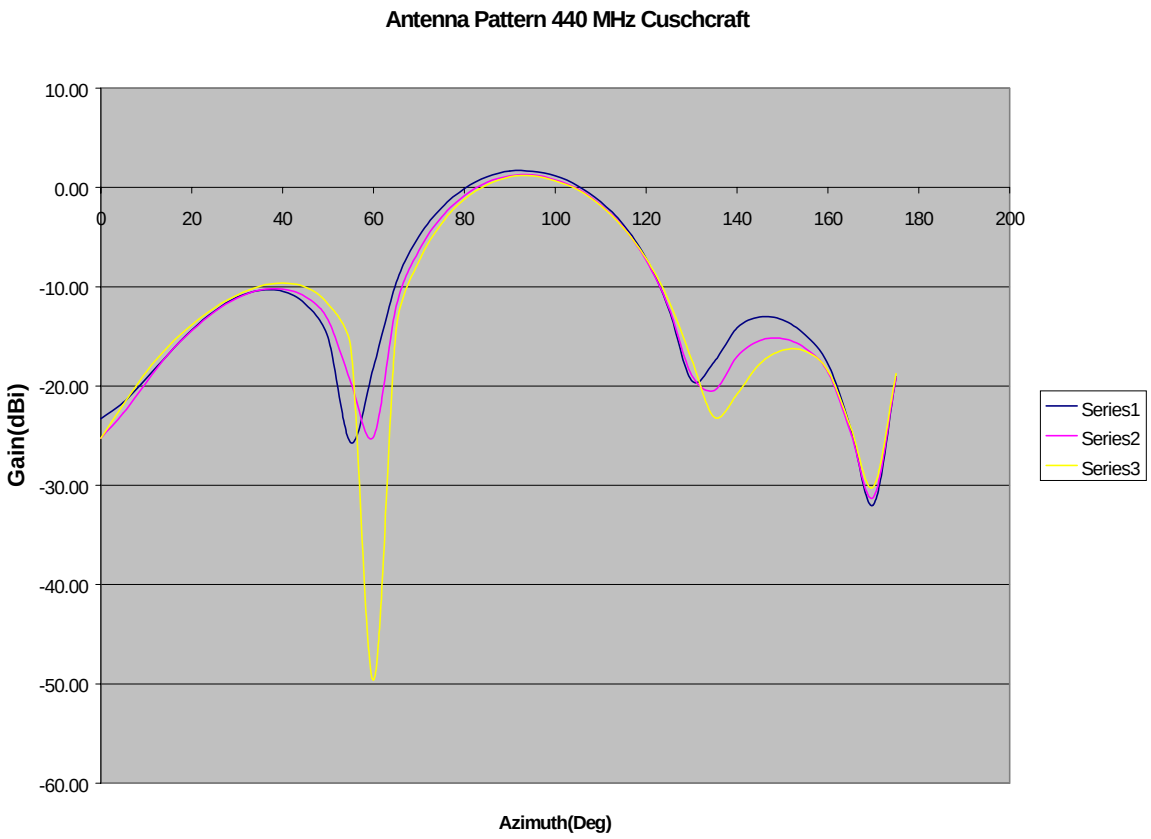

Figure A2. Gain of 440 MHz Cushcraft transmitter dipole (NIST Chamber).

Table A5. Averaged Table Mountain Azimuth Gain Measurements

Frequency(MHz)	Manufacturer	Mounting	Average Gain(dBi) Measured
440	Larson 5/8 λ monopole	Roof	4.1
1360	Larson ¼ λ monopole	Roof	-0.2
1360	Larson ¼ λ monopole	Trailer	-1.7
1920	Andrew PCS monopole	Roof	1.5

The Table Mountain measurements show the effects of the measurement van, shadowing and multipath from the ground reflection. The roof-mounted antennas were shadowed by the van mast at about 180°. This produced a 3 to 5 dB drop for about 10% of the pattern for the 440 MHz roof antenna. The 1360 MHz roof antenna has about 3-dB variability but no apparent shadowing. The 1920 MHz roof antenna has 5 to 10 dB shadowing effects for about 10% of the pattern and 3-dB variability. The 1360 MHz trailer antenna has a 10 dB drop between 0°and 20°, or about 10% of the pattern.

A third set of measurements was completed in the NIST anechoic chamber. A 1.3 m circular ground plane was utilized with the monopole receiving antennas and the vertical

pattern was measured. The vertical pattern of the 440 MHz Cushcraft transmit dipole was also measured with no ground plane. Figures A2 to A5 show the patterns for the four antennas, and Table A6 lists the measured antenna gains.

The gain of the 440 MHz Cushcraft dipole has a broad maximum near 90 degrees (on the horizon). The monopole antenna measurement plane puts 0° on the horizon. Gain for these antennas peak between 15° to 20° although the Larson 5/8 λ monopole has a broad peak near the horizon. The gain versus angle is given in Table A6.

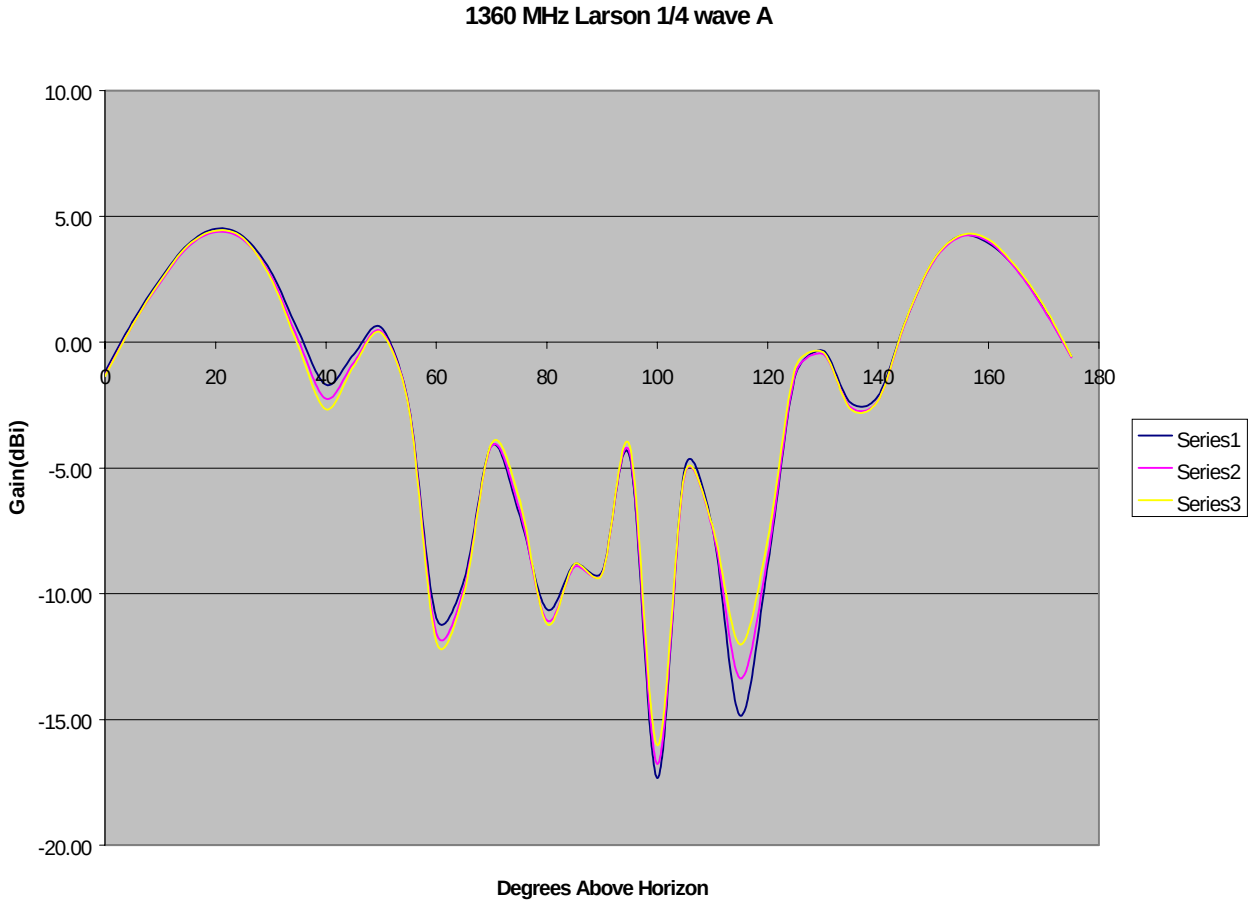

Figure A3. 1360 MHz Larson receiving monopole pattern (NIST Chamber).

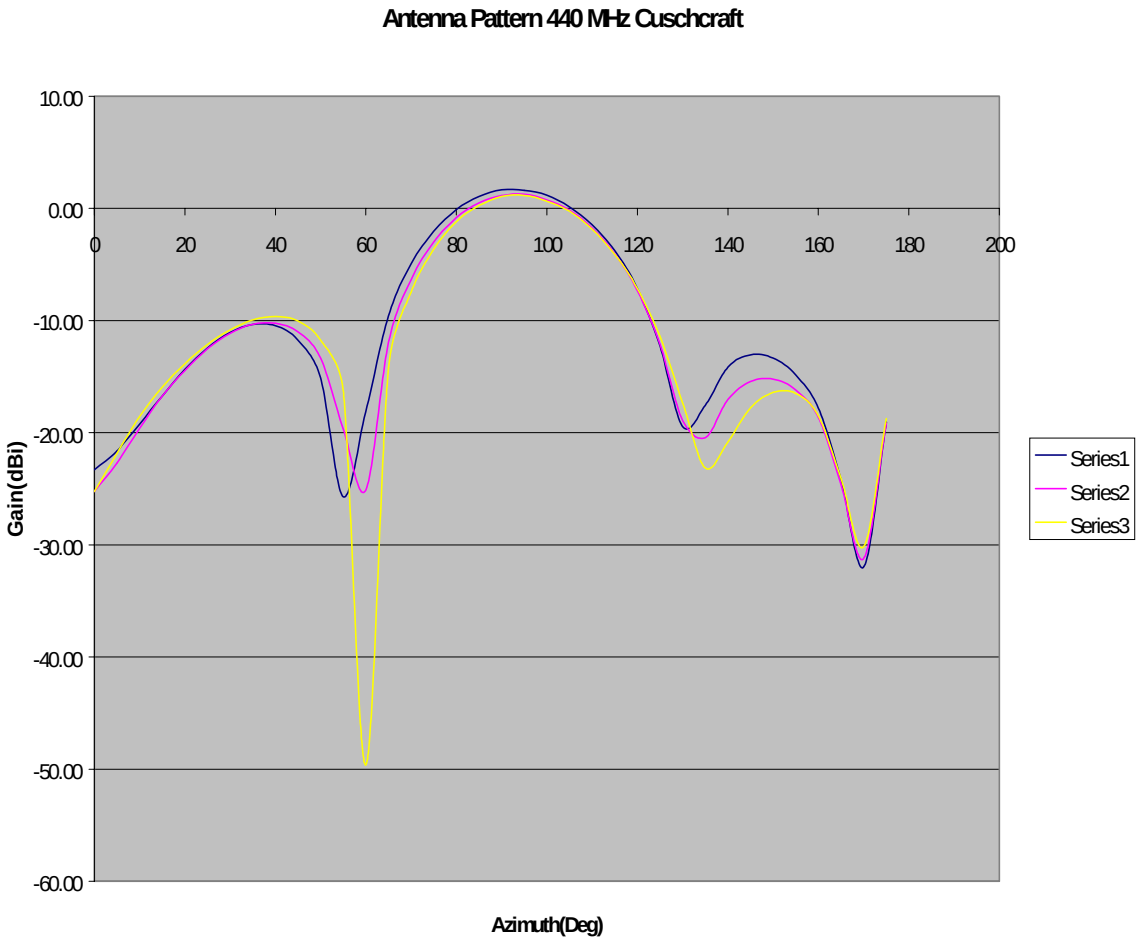

Figure A4. Gain of 440 MHz Cushcraft transmitter dipole (NIST Chamber).

Table A6. Gain Measured in the NIST Anechoic Chamber for the Receiving Monopole Antennas

	Gain(dBi)											
	Larson 440 MHz			Larson 1360 MHz			Andrew 1920 MHz			Cushcraft 440 MHz		
F(MHz)	435	440	445	1355	1360	1365	1915	1920	1925	435	440	445
Elevation (deg)												
0	1.8	1.1	0.8	-1.2	-1.3	-1.4	-0.6	-0.7	-0.9	-23.3	-25.2	-25.2
5	2.4	1.9	1.6	0.8	0.7	0.7	1.5	1.4	1.2	-21.6	-22.7	-21.9
10	2.8	2.3	2.0	2.5	2.4	2.4	3.0	2.9	2.7	-19.2	-19.6	-18.6
15	2.7	2.2	2.0	3.9	3.8	3.8	3.6	3.5	3.3	-16.7	-16.7	-15.9
20	1.9	1.5	1.4	4.5	4.4	4.4	2.7	2.7	2.4	-14.4	-14.4	-13.8
25	0.5	0.1	0.1	4.2	4.1	4.1	-0.4	-0.5	-0.6	-12.4	-12.5	-12.1
30	-2.2	-2.4	-2.1	2.8	2.6	2.5	-8.0	-7.7	-7.5	-11.0	-11.1	-10.8
35	-6.3	-5.8	-5.0	0.4	0.1	-0.2	-8.5	-8.3	-8.3	-10.3	-10.3	-9.9
40	-9.7	-8.2	-6.7	-1.7	-2.3	-2.7	-3.1	-3.1	-3.2	-10.4	-10.2	-9.6
45	-6.3	-6.2	-5.5	-0.5	-0.8	-1.0	-1.7	-1.9	-2.1	-11.7	-11.0	-10.0
50	-3.4	-3.9	-3.9	0.6	0.4	0.4	-3.8	-3.9	-4.0	-15.1	-13.3	-11.7
55	-1.9	-2.8	-3.2	-2.5	-2.6	-2.6	-0.7	-0.7	-0.7	-25.7	-19.6	-16.1
60	-1.6	-2.8	-3.3	-11.0	-11.6	-11.9	-1.9	-2.2	-2.5	-18.1	-25.1	-49.6
65	-2.2	-3.5	-4.3	-9.5	-9.8	-10.0	-4.3	-4.4	-4.7	-9.6	-11.9	-14.2
70	-3.4	-4.9	-5.9	-4.1	-4.1	-4.0	-1.8	-1.7	-1.7	-4.9	-6.3	-7.4
75	-5.5	-7.0	-8.2	-6.8	-6.6	-6.2	-9.2	-9.7	-10.3	-2.0	-3.0	-3.6
80	-9.0	-10.6	-11.9	-10.6	-11.1	-11.2	-11.2	-11.6	-12.0	-0.1	-0.8	-1.2
85	-15.7	-17.6	-19.0	-8.8	-8.9	-8.8	-4.7	-4.8	-4.9	1.1	0.5	0.3
90	-22.1	-23.1	-24.1	-9.1	-9.2	-9.2	-4.3	-4.3	-4.3	1.7	1.2	1.1
95	-11.5	-12.9	-13.9	-4.5	-4.4	-4.1	-4.5	-4.4	-4.4	1.6	1.3	1.2
100	-6.9	-8.3	-9.3	-17.3	-16.8	-16.0	-11.1	-11.6	-12.2	1.2	0.8	0.7
105	-4.4	-5.6	-6.4	-5.0	-5.3	-5.2	-2.4	-2.4	-2.3	0.2	-0.2	-0.2
110	-2.8	-3.9	-4.5	-7.4	-7.4	-7.3	-2.5	-2.4	-2.5	-1.4	-1.7	-1.8
115	-2.0	-2.8	-3.1	-14.9	-13.4	-12.0	-2.1	-2.3	-2.5	-3.8	-4.0	-4.1
120	-1.9	-2.5	-2.6	-8.9	-8.5	-7.8	-0.3	-0.2	-0.2	-7.2	-7.3	-7.1
125	-2.9	-3.2	-3.0	-1.3	-1.3	-1.0	-1.4	-1.3	-1.3	-12.3	-12.1	-11.4
130	-5.3	-5.0	-4.3	-0.3	-0.5	-0.4	-0.4	-0.5	-0.7	-19.5	-18.9	-17.3
135	-9.0	-7.5	-5.9	-2.4	-2.6	-2.7	-0.6	-0.7	-0.9	-17.6	-20.4	-23.1
140	-7.7	-6.4	-5.2	-2.1	-2.3	-2.3	-4.3	-4.1	-4.0	-14.1	-17.0	-20.8
145	-3.0	-2.9	-2.5	0.9	0.8	0.9	-5.2	-4.9	-4.6	-13.1	-15.4	-17.8
150	0.1	-0.1	0.0	3.2	3.2	3.3	-0.7	-0.6	-0.6	-13.3	-15.2	-16.4
155	2.0	1.7	1.6	4.2	4.2	4.3	2.1	2.0	1.9	-14.9	-16.2	-16.5
160	3.1	2.6	2.5	3.9	4.0	4.1	3.4	3.2	3.1	-17.8	-18.6	-18.5
165	3.4	2.9	2.7	2.9	2.9	3.0	3.9	3.7	3.5	-24.3	-24.7	-24.1
170	3.3	2.7	2.5	1.3	1.3	1.4	3.8	3.7	3.5	-31.9	-31.2	-30.2
175	2.8	2.2	1.9	-0.6	-0.6	-0.6	3.0	2.9	2.8	-19.0	-19.1	-18.7

The gain on the horizon (0°) as measured in the anechoic chamber was used for data reduction. Data from the chamber for the Cushcraft 440 MHz dipole also was used. The azimuth pattern for the 1360 MHz dipole was used when reducing the data. This pattern was obtained from the manufacturer and also verified by measurements but not presented here. Table A7 and Table A8 give the gain and azimuth patterns used for data reduction.

Table A7. Receiving Antenna Gain

Receive Antenna Gains			
Frequency(MHz)	Manufacturer	Gain (dBi)	Azimuth Pattern
440	Larson	1.2	Omni
1360	Larson	-1.3	Omni
1920	Andrew	-0.7	Omni

Table A8. Transmitting Antenna Gain

Transmit Antenna Gains			
Frequency(MHz)	Manufacturer	Gain (dBi)	Azimuth Pattern
440	Cushcraft	1.7	Omni
1360	Dorne&Margolin	11.3	Table Lookup
1920	Andrew	6.9	Omni

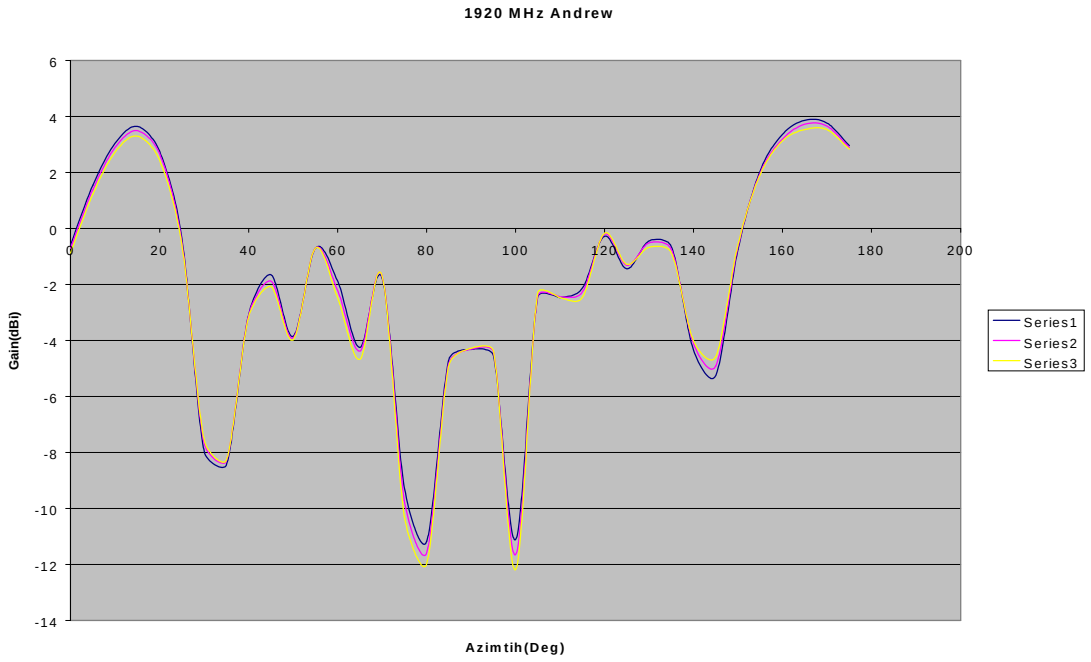

Figure A5. 1920 MHz Andrew receiving monopole (NIST Chamber).